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RESEARCH MEMORANDUM

TRANSONIC FLIGHT TEST OF A ROCKET-POWERED MODEL TO DETERMINE PROPULSIVE JET INFLUENCE ON THE CONFIGURATION DRAG

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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TRANSONIC FLIGHT TEST OF A ROCKET-POWERED MODEL TO DETERMINE PROPULSIVE JET INFLUENCE ON THE CONFIGURATION DRAG

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SUMMARY

A rocket-powered cone-cylinder body with a conical boattail was flight-tested to determine the jet interference effects on the configuration drag at transonic Mach numbers. It was found that an overexpanded nozzle could increase the boattail pressure drag at transonic Mach numbers whereas only an underexpanded nozzle affected the boattail drag at Mach number 1.59 (see NACA RM L54C16) and then it reduced the drag. Similar to the supersonic test, the overexpanded jet decreased the base pressure relative to the power-off value, increasing the drag.

Under the conditions of the present tests, the power-on drag was consistently higher than the power-off drag. At a Mach number of 1.075, this increase amounted to 0.107, which was more than 24 percent of the power-off drag. Allowing for the increase in base drag coefficient of 0.022, the estimated boattail drag coefficient increase of 0.012, and twice the error in determining the thrust that is believed to exist, there remains a total-drag increase (of the same magnitude as the base-drag increase) that cannot be accounted for as an increase in body drag and is apparently, therefore, an increase in the fin and fin-interference drag.

INTRODUCTION

Considerable interest has been shown in the effects of a propulsive jet on the external drag of the housing for turbojet and rocket motors. This interest has manifested itself in references 1 to 5, where it has been shown that appreciable drag savings or drag penalties are to be obtained, depending on the afterbody configuration, nozzle design, and jet operating conditions.

To date, no theoretical approach to the prediction of these jet effects has been forthcoming; hence, total reliance has been placed on experiment. References 1, 2, and 4 are systematic studies of various phases of the general subject and were conducted at supersonic Mach numbers. No such systematic study has been made for the transonic range, although reference 3 does present data for transonic Mach numbers. Accordingly, the present test was made, on a cone-cylinder body with a conical boattail in an effort to tie the transonic problem to the more complete investigations at supersonic Mach numbers.

This test was conducted on a free-flight rocket-powered model at the Pilotless Aircraft Research Station at Wallops Island, Va. The Mach number range was from 0.8 to 1.2 and the Reynolds number range was from 23×10^6 to 43×10^6.

SYMBOLS

A	area, sq ft
A_{max}	maximum cross-sectional area, sq ft
a	acceleration, ft/sec^2
g	acceleration due to gravity, ft/sec^2
γ	ratio of specific heats
x	body station, in.
l	body length, in.
M	Mach number
p	static pressure, lb/sq in. abs
R	Reynolds number based on body length
C_p	pressure coefficient, $\dfrac{p - p_o}{q_o}$
C_D	drag coefficient, $\dfrac{D}{q_o A_{max}}$
q_o	dynamic pressure, lb/sq in.
T	thrust, lb

D drag, lb

W weight, lb

θ flight-path angle, deg

α nozzle-divergence half angle

λ thrust correction for nozzle divergence, $\frac{1}{2}(1 + \cos \alpha)$

Subscripts:

o free stream

j jet

b base

1,2 boattail orifice locations

MODEL AND TESTS

The model used in this test was a 3.5 scale-up of body 3 in reference 1. It was a cone-cylinder with a conical afterbody section to which four stabilizing fins were attached (fig. 1). Both the nose and afterbody sections had a conical taper of 10°. The stabilizing fins were 60° deltas with a 4-percent double-wedge section in the stream direction. The model was 66.11 inches long with a fineness ratio of 7.87. Figure 2 is a photograph of the model and booster combination on the launcher.

Afterbody, base, and jet pressures were measured at the orifices shown in figure 1.

The jet nozzle was a convergent-divergent type of nozzle with a 10° conical section from the throat to the exit. The solid propellant was a modified 5-inch British Cordite. The gas generated from burning this propellant has a ratio of specific heats γ of 1.25. Inasmuch as the ratio of nozzle exit to throat area was 5.25, the jet-exit Mach number was 2.91.

Data from the model instruments were telemetered continuously to the ground receiving station. The model velocity was obtained from a CW Doppler radar set while the atmospheric data necessary to obtain Mach

number and pressure coefficients were obtained from the NACA modified SCR-584 radar in conjunction with radiosonde observations made at the time of launching.

The Mach number range of this test was from 0.8 to 1.2. The Reynolds number based on body length varied from 32×10^6 to 43×10^6 in power-on flight and from 43×10^6 to 23×10^6 in power-off flight, as indicated in figure 3. Thus, presumably, the boundary layer was turbulent at the base.

It is believed that the accuracy of the Doppler radar and radiosonde data yields Mach numbers correct within ±0.01 and that the pressure readings yield C_p within ±0.008.

ANALYSIS

In order to determine the drag of a thrusting configuration, it is necessary to know the thrust and the net acceleration of the configuration. The drag may then be evaluated according to the equation

$$D = T - \frac{W}{g}(a + g \sin \theta) \tag{1}$$

In a flight model the thrust may be determined from the measurement of the jet exit pressure; whereas the acceleration and flight path angle are measured directly. As the thrust is larger than the drag, the accuracy in determining the power-on drag is related to the accuracy in computing the thrust. Accordingly, the rocket motor was first ground-tested so that the thrust calculated from the equation

$$T = p_j A_j \left(\lambda \gamma_j {M_j}^2 + 1\right) - p_o A_j \tag{2}$$

could be checked with the measured thrust. As shown in figure 4, the agreement was very good. Thus, the power-on drag coefficient could be determined from the equation

$$C_D = \left(\frac{A_j}{A_{max}}\right)\left(\frac{1}{0.7M_o^2}\right)\left[\frac{p_j}{p_o}\left(\lambda\gamma_j M_j^2 + 1\right) - 1\right] - \frac{1}{0.7p_o M_o^2 A_{max}}\left(\frac{W}{g}\right)(a + g \sin \theta) \quad (3)$$

Figure 5 presents the free-stream pressure p_o and the jet pressure ratio p_j/p_o as a function of the flight Mach number M_o.

RESULTS AND DISCUSSION

Coefficients from the measured pressures from the two boattail orifices are plotted in figure 6 against free-stream Mach number. Interference effects from the propulsive jet, where present, act in such a manner as to decrease the pressure and hence increase the drag. This effect appears, however, to be limited to subsonic and transonic flows since, at a Mach number of 1.15, the power-on and power-off pressure coefficients are identical at orifice 2 and are approaching equality at orifice 1. No jet interference was noted in reference 1 except at the higher jet pressure ratios, and then the effect was to increase the boattail pressures. As the jet pressure ratio of the present tests varied from 0.75 to 0.86, it appears that the combined ejection action of the jet and external flows, described in reference 1, is more readily able to alter the steeper boattail pressure gradients of subsonic and transonic Mach numbers.

The effect of the jet in this jet pressure range was, as in reference 1, to lower the base pressure (fig. 7(a)). Decreasing the flight Mach numbers below 0.95 or increasing them above 1.0 has the effect of increasing the difference between the power-on and power-off base pressures. The subsonic reaction of the base pressure to the jet flow is similar to that of the boattail pressures. However, although an increase in supersonic Mach number decreased the influence of the jet on the boattail pressures, it markedly increased its influence on the base pressure.

Base drag coefficients resulting from the above are shown in figure 7(b). This drag increases with Mach number from a negative drag, or thrust, at subsonic Mach numbers to an increasing drag with supersonic Mach numbers. Interference effects of the jet increased the base drag over the entire Mach number range. The jet interference at Mach number 1.15 more than doubled the base drag, although the annulus area was but 60 percent that of the base area.

Jet interference effects on the total drag of the configuration are shown in figure 8. The power-on drag is considerably higher than the power-off drag over most of the Mach number range. The amount of this increase introduced by the increase in base drag is indicated by the circular symbols. The remainder of the drag increase can be due to any one or a combination of the following:

(a) Increase in boattail pressure drag
(b) Increase in boattail friction drag
(c) Increase in body friction drag due to change in Reynolds number
(d) Increase in fin and fin interference drag
(e) Inaccuracy in determining the thrust

An estimation was made at a Mach number of 1.075 of the increase in boattail pressure and friction drags due to jet interference effects. The increase in the pressure drag coefficient was estimated to be small (0.006) owing to the small area involved. However, it is not impossible that the boattail pressures in the region of the fins (where the fin interference effects would be the largest) were affected to a greater extent than were those measured 45° between the fins. Inasmuch as measurements were not made in the region close to the fins, such a change would have to be included in the fin interference drag. Interference effects of the jet in reducing the adverse pressure gradient over the boattail might decrease the boundary-layer thickness while increasing the local velocities. Such a combination would tend to increase the friction drag. Once again, however, the area involved is small and the estimated increase in friction drag coefficient of 0.006 is felt to be higher than would actually exist. The flight path of the present tests was such that, for a given Mach number, the power-on Reynolds number was higher than the power-off Reynolds number (fig. 3). In this range of Reynolds number, such a change would result in less skin friction drag with power on than with power off; hence, effectively; the difference between the power-on and power-off total drags would be increased. However, the change would be small and has consequently been neglected. As no measurements were made on the fins, there is no way of directly estimating any influence of the jet on their drag. Adding the above estimates of the boattail-drag-coefficient increase to the 0.022 increase in base drag, at $M_0 = 1.075$, results in an estimated increase in drag coefficient of 0.034. Subtracting this increment from the 0.107 increase in total drag leaves an increase of 0.073 unaccounted for by body-drag increase.

Figure 4 indicates a probable difference of ±15 pounds and a maximum difference of 30 pounds between the thrust computed from equation (2) and that measured on a stand accurate to ±2 percent. If, at a Mach number of 1.075, the thrust computed from the measured jet exit pressure were 15 pounds high, the correct power-on drag coefficient would be 0.025 lower than that shown in figure 8. Then the unaccounted-for increase in

drag coefficient would be reduced to 0.048. If, however, the computed thrust were 30 pounds high, the power-on drag coefficient should be 0.050 lower and the unaccounted-for increase in drag coefficient would be 0.023, or equal to the base-drag increase. In order to reduce the power-on drag coefficient to a value that can be attributed to the increase in boattail and base drags, the computed thrust must be 45 pounds high. Indeed, except from Mach number 0.95 to 1.0, a thrust decrease of the same order would yield a power-on drag curve entirely accountable to the estimated increases in body drag. Such a change would not be random but rather would always be in one direction. However, the results of the ground tests (fig. 4) indicate that equation (2) yields the thrust to a greater degree of accuracy than this, if the jet exit pressure measurement is correct, and that any error is random in nature. As this measurement agreed within ±0.2 pound per square inch absolute with the base pressure measurement, both prior to and after sustainer fire, it is not believed that the necessary error of more than 10 times this difference would occur only during sustainer fire. In view of these arguments, and allowing for twice the error in determining the thrust that is thought to exist, there still remains a drag increase due to propulsive jet interference, of the same order as the base-drag increase, which cannot be accounted for by the estimated body-drag increase. Hence, it apparently is an increase in the fin and fin-interference drag.

Further evidence that this represents an increase in fin and fin-interference drag is to be had from a comparison of figures 6 and 8 and the fact that the fin trailing edge is at station $x/L = 1.0$. When boattail orifice 1 shows no difference between power-on and power-off pressures, total drags may be wholly accounted for by the increase in base drag. When there is a difference between the power-on and power-off boattail pressures, the increase in total drag is larger than can be attributed to the body-drag increase.

CONCLUDING REMARKS

In summarizing the results of the present tests, certain findings are of particular interest as they were not noted in the supersonic tests previously made of a smaller model of the present configuration. In the transonic Mach number range of the present tests, the overexpanded jet of Mach number 2.82 influenced the boattail and base pressures in such a manner as to increase their pressure drags, whereas at free stream Mach number 1.59 with the smaller model (NACA RM L54C16) the jet interference only occurred at high jet pressure ratios with the jet Mach number of 2.65 and always increased the boattail pressures. In the present tests up to Mach number 1.2, the influence of the jet was present and decreased the boattail pressures. Apparently, then, this is a subsonic and transonic phenomenon. In contrast, the base pressures of the

two tests reacted in a similar manner in both tests. Changing the Mach number in either direction from 0.98 results in a base pressure that decreases relative to its power-off value.

Under the conditions of the present tests, the power-on drag was consistently higher than the power-off drag. At a Mach number of 1.075, this increase in drag amounted to 0.107, which is more than 24 percent of the power-off drag. Allowing for an increase in the base drag coefficient of 0.022, an estimated boattail drag coefficient increase of 0.012, and twice the error in determining the thrust that is believed to exist, there still remains a total-drag increase (of the same magnitude as the base-drag increase) that connot be accounted for as an increase in body drag and hence is apparently an increase in fin and fin-interference drag.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 13, 1954.

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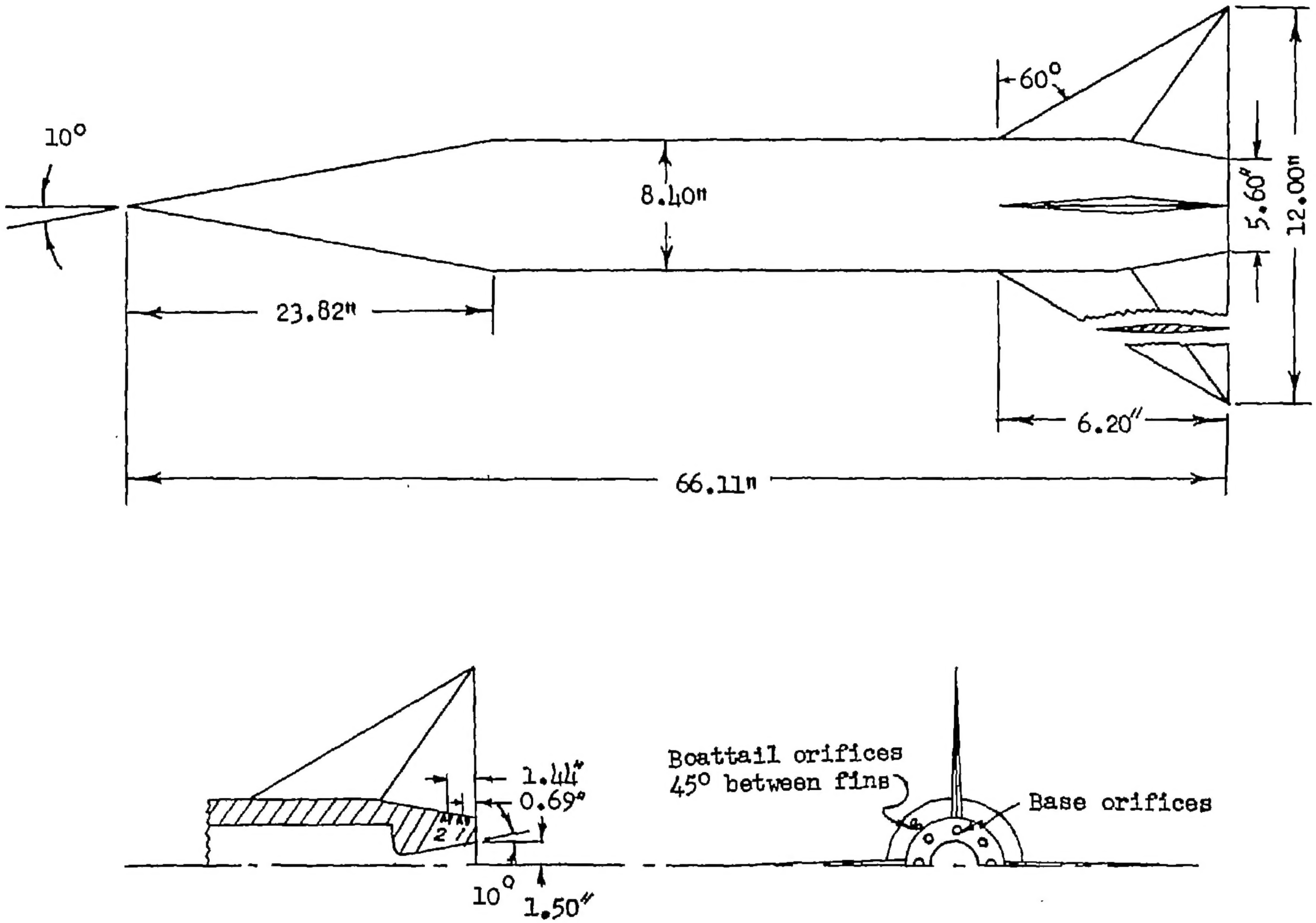

Figure 1.- Sketch of configuration.

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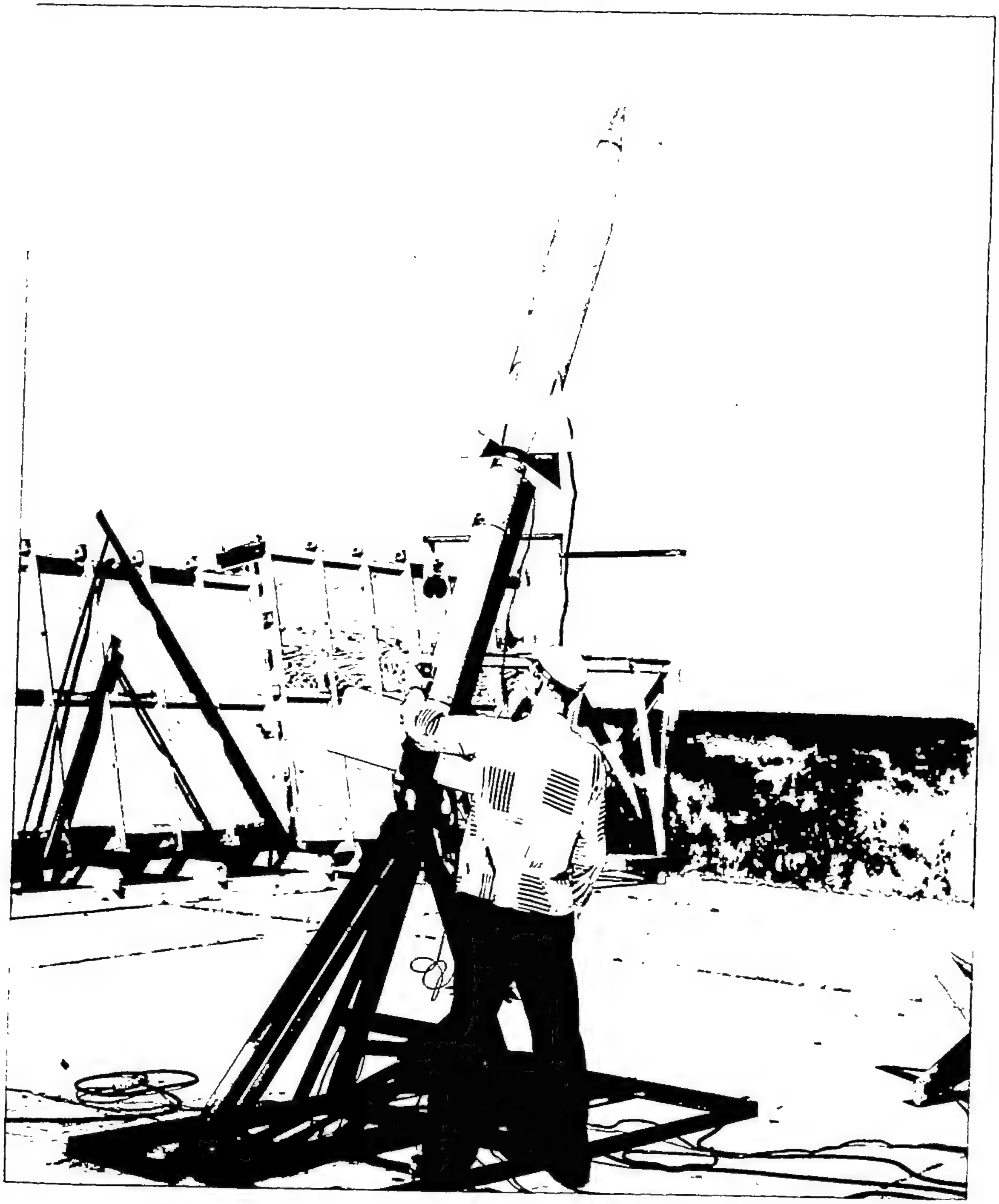

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Figure 2.- Photograph of model and booster prior to launching.

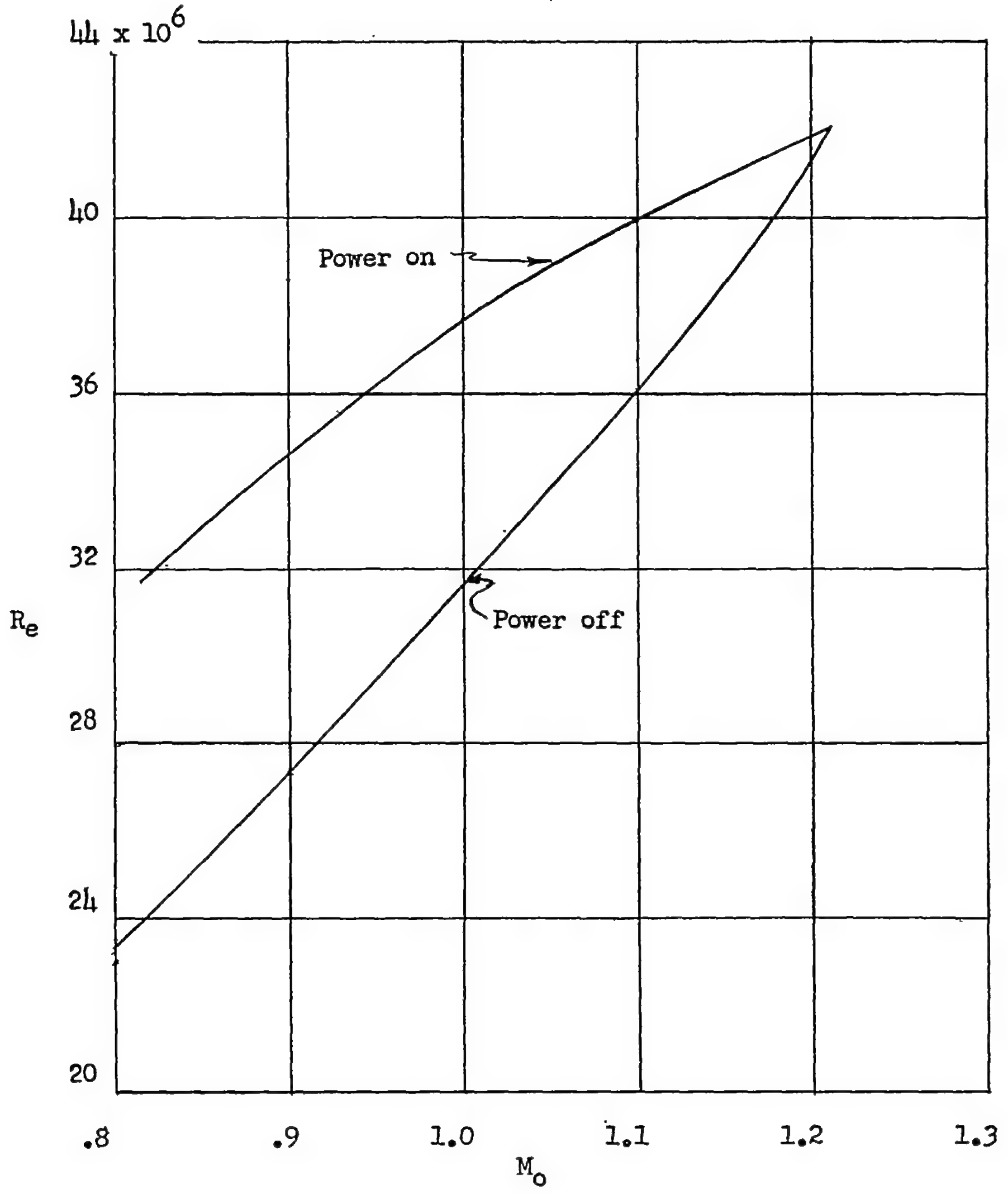

Figure 3.- Variation of Reynolds number with Mach number.

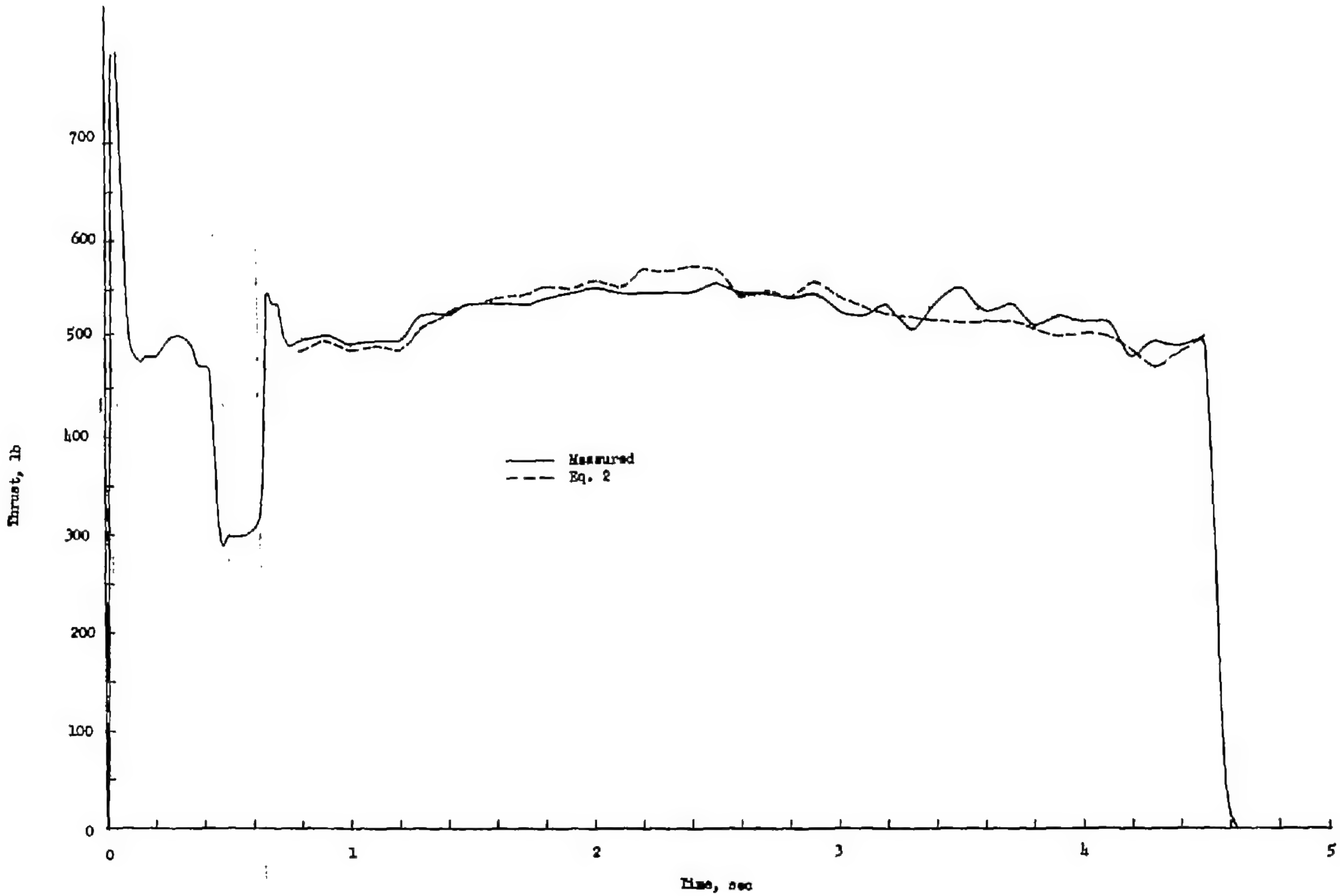

Figure 4.- Comparison of computed and measured static thrust.

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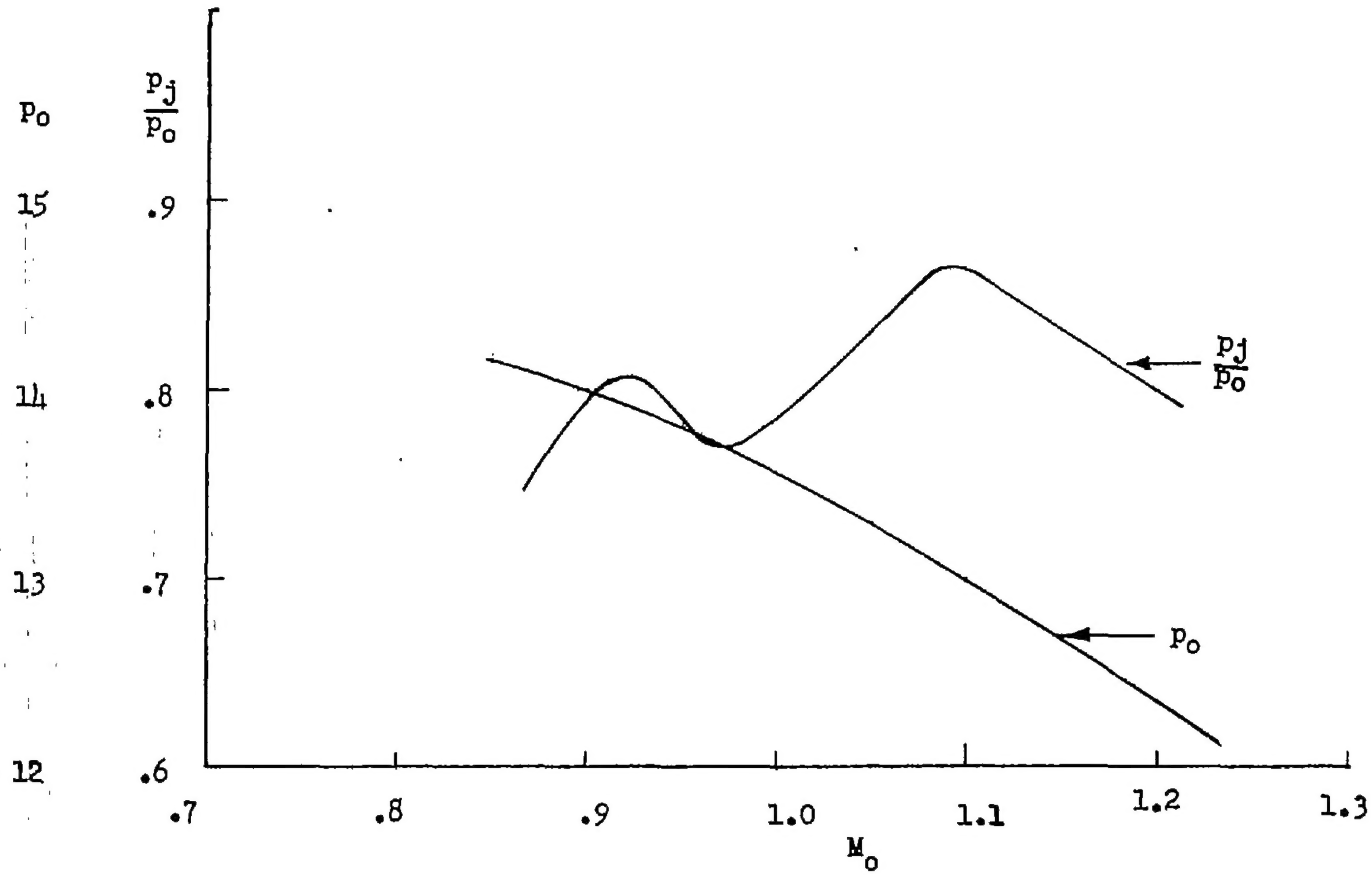
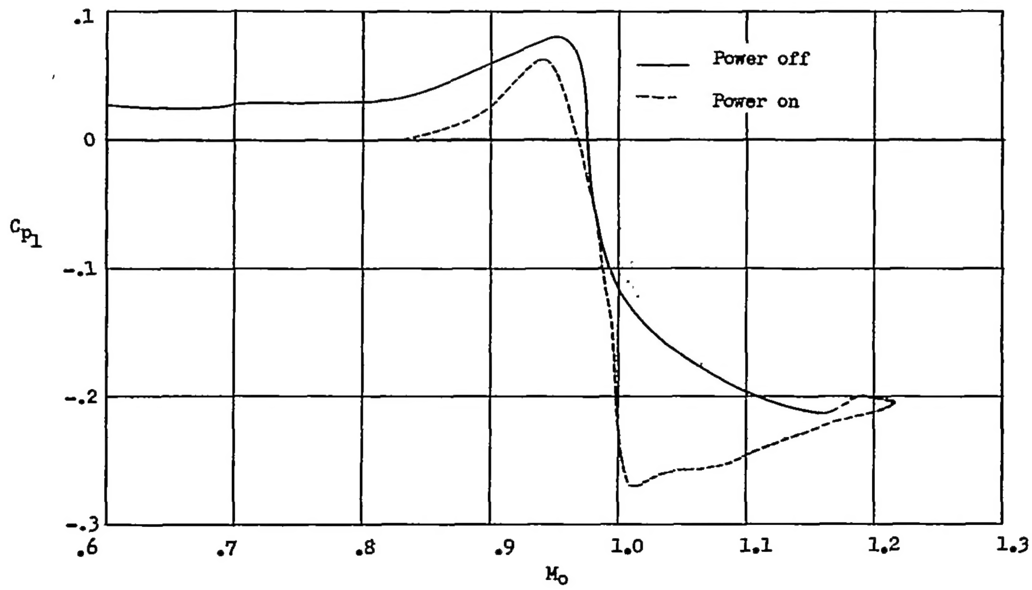
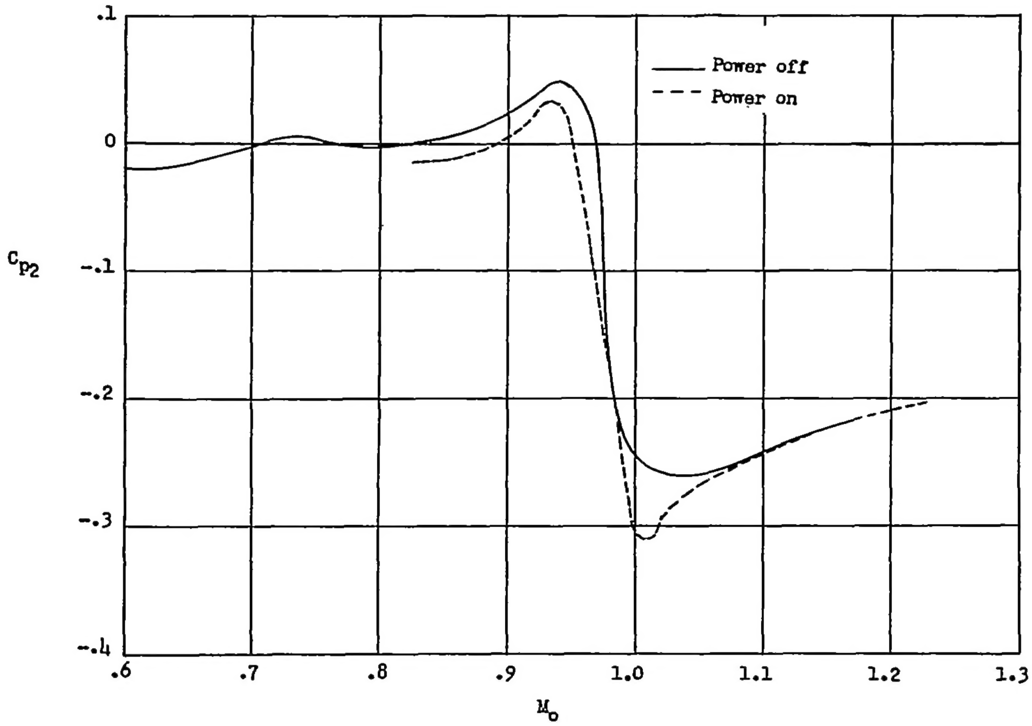


Figure 5.- Free-stream pressure and jet pressure ratio.

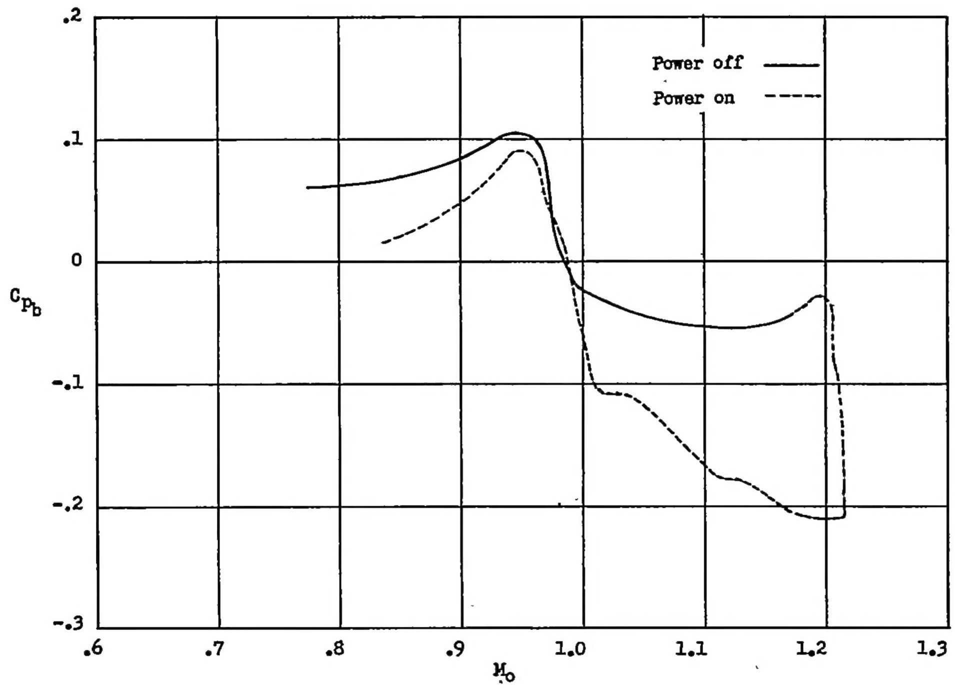


(a) Boattail pressure orifice 1.

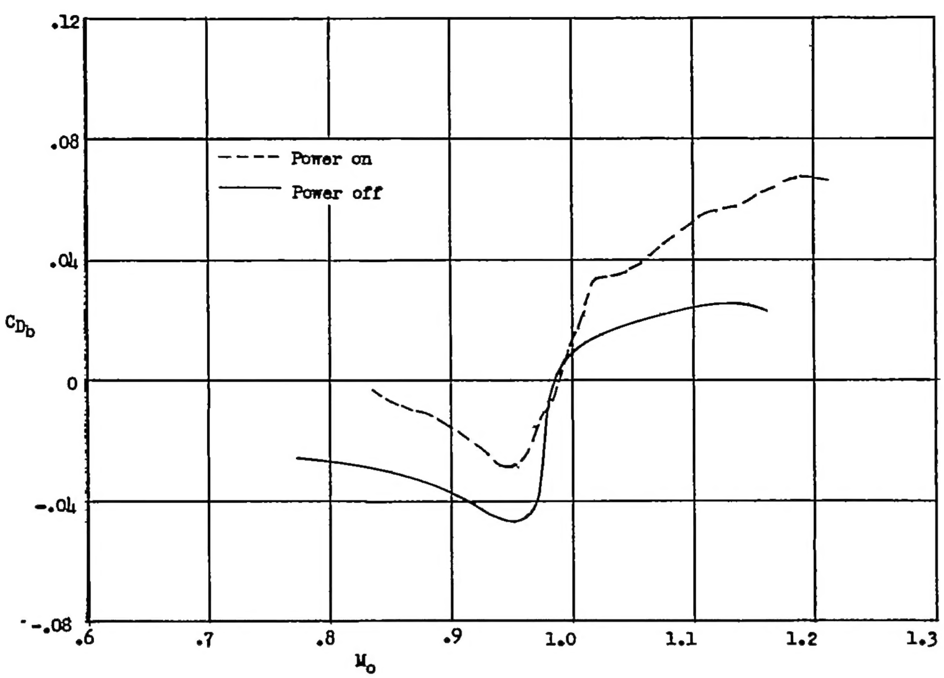


(b) Boattail pressure orifice 2.

Figure 6.- Boattail pressure coefficients as a function of flight Mach number.



(a) Base pressure coefficient.



(b) Base drag coefficient.

Figure 7.- Base pressure and drag coefficients.

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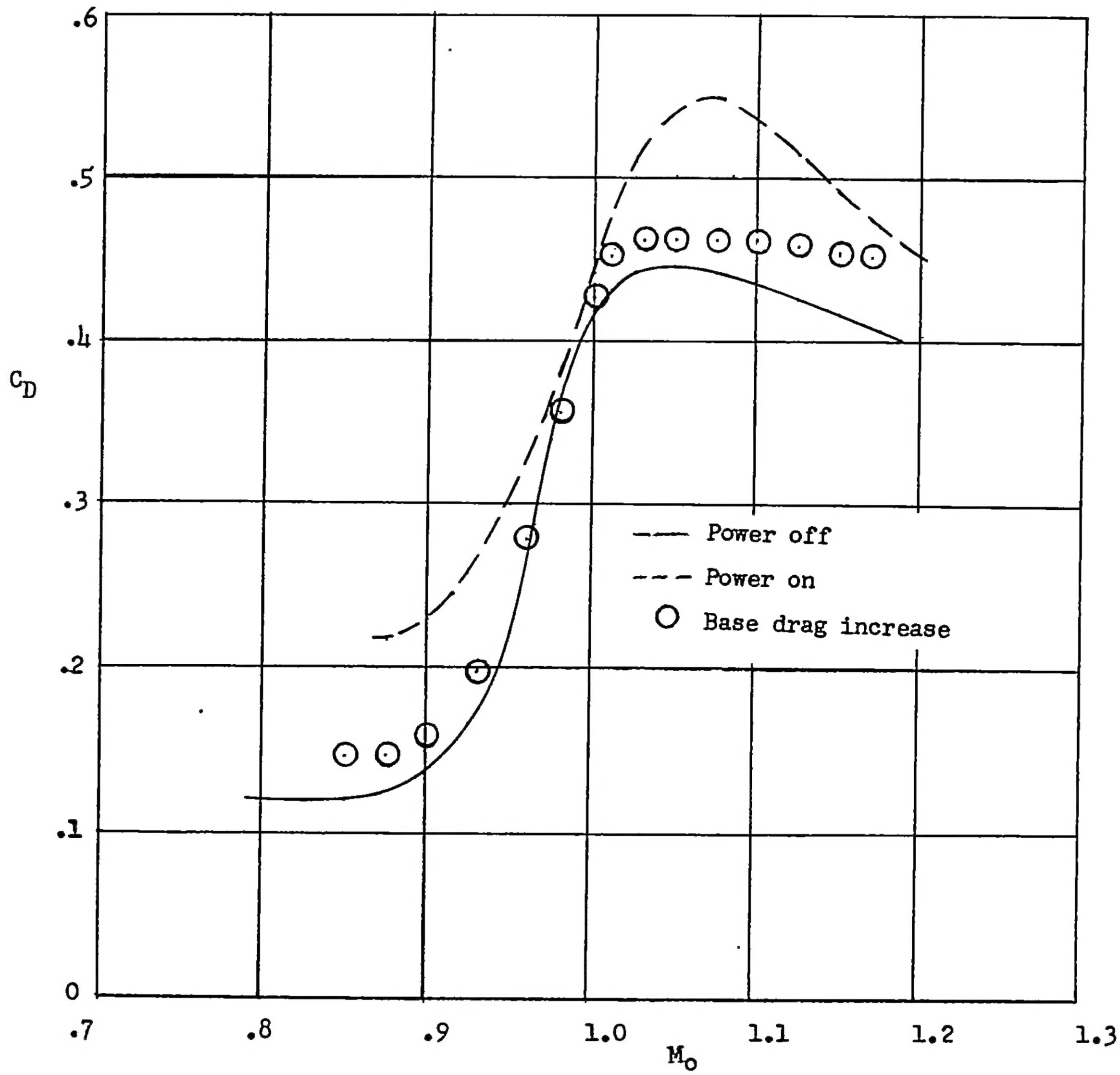

Figure 8.- Total drag coefficient.